Papers and Originals

Radio-frequency Hazards with Cardiac Pacemakers

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Burchell (1961) and Weinberg *et al.* (1962) have ably described some of the dangers associated with the use of cardiac pacemakers, and emphasized the need for having all electrical apparatus using alternating current carefully earthed before bringing it near a patient who has, or is having, a pacemaker embedded to control his heart rate. Noordijk *et al.* (1961) reported on two patients with embedded pacemakers who developed ventricular fibrillation while electrocardiographic tracings were being taken with a machine which was inadequately earthed.

We have recently encountered a further hazard associated with the use of certain types of apparatus in patients having the heart paced by some makes of artificial pacemaker. Such patients may develop ventricular fibrillation when near any apparatus transmitting radio-frequency waves, such as are emitted by a surgical diathermy machine, a physiotherapy induction diathermy machine, a Hyfrecator, certain types of ultra-violet-light machines, neon advertising lights, a betatron unit, or a radio-transmitting station.

Pacemaker stimulation by means of an intracardiac electrode and external pacemaker is often used as a preliminary to inserting an implantable pacemaker. This is a well-established procedure and has brought patients out of cardiac or renal failure, and improved their general condition, prior to the definitive operation. Even when preliminary intracardiac stimulation is not required to improve the patient's condition, it is often used as a safeguard during induction of anaesthesia and the implanting of a pacemaker.

In our unit we have used this precaution routinely. As a rule the intracardiac catheter is inserted a day or two before operation, and external pacing is then begun and monitored up to and during the time of operation, until the implantable pacemaker is in position. The external pacemaker is disconnected immediately prior to connecting the second cardiac electrode to the implantable pacemaker, and the intracardiac catheter is then removed.

Because of the previously described hazards with pacemakers using alternating current from wall mains, we have used pacemaker units employing transistors and powered by batteries. These units provide an impulse via the intracardiac catheter to the right ventricle.

During operations surgical diathermy apparatus is commonly used for cutting and coagulating. This is routine in all our thoracic surgical procedures, including heart operations, and is safely employed even for opening the pericardium.

Our attention, however, was recently drawn to the danger of radio-frequency current when two patients with heart-block controlled by means of bipolar intracardiac catheter electrode and an external battery-operated transistor pacemaker developed ventricular fibrillation when diathermy was used during thoracotomy to suture implantable pacemaker leads to the myocardium.

Subsequent experiments in sheep and dogs have confirmed the danger of using surgical diathermy for thoracotomy in the presence of intracardiac stimulation by certain makes of pacemaker, and have demonstrated that the same hazard exists with other apparatus emitting radio-frequency waves.

We have further established that when a surgical diathermy machine—having absolutely no physical contact with the subject by either its positive or indifferent electrodes—is operated within 3 ft. (90 cm.) of a heart paced by these pacemakers the radio-frequency waves may cause a great increase in the pulse rate of the pacemaker, which consequently supplies a fibrillating current to the ventricle. This same danger was shown to exist with other apparatus tested. These hazards were demonstrated with the two types of pacemaker used in our unit. Experiments were later carried out with a wider variety of pacemakers, and it was shown that some pacemakers are free of these risks.

The following case reports and experiments illustrate these serious hazards.

Case Reports

Case 1

A man aged 68 was admitted to hospital on 24 January 1964 with heart-block and a pulse rate of 25/min. He had right heart failure and poor renal function. As he failed to respond to medical measures, on 28 January an intracardiac bipolar catheter electrode was inserted into the right ventricle via the left external jugular vein. This was connected to a battery-operated transistor pacemaker at a rate of 70/min. with a 1-volt stimulus and 5 millisecond pulse duration. The pacemaker was the I.M.E. model made by the Genito-Urinary Manufacturing Co., London: G.U. 2371.

From 1 to 9 February he was satisfactorily paced, and his cardiac and renal function improved. On 10 February a thoracotomy was performed for the insertion of an Elema-Schönander implantable pacemaker. A left upper paramedian incision was made, and a pocket was fashioned behind the rectus muscle to receive the pacemaker. A left submammary thoracotomy was then performed and the pericardium exposed. Surgical diathermy was used for the thoracotomy incision.

The chest wall was opened without incident. However, during the opening of the pericardium with the diathermy point ventricular fibrillation occurred. Cardiac massage was immediately instituted, and after two defibrillating shocks with an A.C. defibrillator heart arrest occurred and was followed by the return of spontaneous heart-beats. During the defibrillation the external pacemaker controlling

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the intracardiac electrode was switched off. The spontaneous beat when reinstituted showed a 2:1 heart-block as before, and this was corrected by again switching on the external pacemaker. The implantable pacemaker electrodes were thereafter attached to the heart, and the Elema-Schönander pacemaker unit was implanted behind the left rectus abdominis muscle.

During the opening of the chest it had been noted that, whenever the diathermy current was switched on, an audible buzzing sound was transmitted from the external pacemaker loud-speaker. This speaker, on the I.M.E. unit used, gives an audible "pip," indicating that the unit is pacing, and allows the rate to be checked. It was thought that the "buzz" was only an interference with the loud-speaker system, but the anaesthetist had the impression that it was also producing a momentary pulse irregularity. The E.C.G. pattern as seen on the cardioscope was, as always, destroyed when the diathermy was used.

The patient made a satisfactory recovery from the operation and no further episodes of ventricular fibrillation occurred. He continues well.

This experience indicated that there might be some association between the use of the diathermy on the pericardium and the onset of ventricular fibrillation. We knew of no reports of difficulties from using diathermy apparatus, nor had our thoracic surgical colleagues in New Zealand noted it. As cardiac standstill or ventricular fibrillation is known to occur during operations for implanting pacemakers (Swedberg *et al.*, 1963), it seemed likely that the association was coincidental, but we thought it advisable not to use diathermy *for the opening of the pericardium* in future operations of this kind.

Case 2

A man aged 68 was referred for implantation of a pacemaker because of complete heart-block, not controlled by medical means.

On 5 July 1964, under local anaesthesia, an intracardiac bipolar catheter electrode was inserted into the right ventricle. This was connected to the same battery-driven transistor external pacemaker (I.M.E. model) with a rate of 70/min., and 1.5-volt stimulus at 5 msec. pulse duration.

On 7 July an implantable pacemaker was inserted. Diathermy was used for the left thoracotomy, and as the thorax was opened it was noted that the cardiac pulsation seen through the intact pericardium was feeble. Ventricular fibrillation set in almost immediately. The pericardium was rapidly opened, and cardiac massage instituted. Over the next hour frequent A.C. electrical defibrillation was attempted, using also serial defibrillating shocks after the Wiggers technique. The ventricular fibrillation proved most refractory to continuous cardiac massage, defibrillation, intracardiac calcium chloride, adrenaline, and intravenous procainamide (Pronestyl). Finally, after correcting the blood *p*H with an injection of sodium bicarbonate solution the heart reverted to standstill and a good heart-beat was restored. The patient remains well.

Comment

In view of these experiences it was decided to undertake experiments to confirm and determine the nature of the hazard associated with the use of diathermy. It seemed possible that the diathermy current might alter the normal rhythm of the battery-operated external transistor pacemaker used. The mechanism appeared to be a feed-back of the diathermy current through the bipolar intracardiac electrode into the pacemaker. It is now established that the diathermy current affects the operation of the transistors and thus greatly increases the rate at which pulses are generated. This occurs even when the pacemaker is set as low as 1.5 volts. Further questioning of colleagues and search of the literature failed to disclose any similar experiences with a pacemaker. Dr. Burchell (personal communication, 1964) had not encountered it, nor was it mentioned in the instructions given with the Elema-Schönander implantable pacemakers.

Experiments were designed to test the effects of surgical diathermy and physiotherapy short-wave diathermy apparatus on the artificially paced heart. Other apparatus using high-frequency oscillators was also tested.

Surgical Diathermy

Surgical diathermy incorporates electrocoagulation and electrosection, using current of extremely high frequency in the range of 500 to 2,500 k.c./sec. This is a radio-frequency current.

The circuit used is from the radio-frequency generator machine to the patient via the active needle-point electrode, through the patient, and back to the machine through a large "indifferent" electrode.

Originally the oscillators for both cutting and coagulation were of the spark-gap type. In some makes the spark-gaps have been replaced by oscillators for cutting currents, retaining spark-gaps for coagulation. Small transmitting valves are normally used in the valve oscillator, and the high-tension power supplies for the oscillator may be unrectified alternating current, unsmoothed unidirectional current, or direct current.

Experiment I.—3 August 1964. A sheep was anaesthetized, placed on an "indifferent" diathermy plate, a right thoracotomy performed, the heart exposed, and an intracardiac bipolar catheter electrode inserted into the right ventricle via the right external jugular vein. The normal heart rate of 112/min. was controlled by the I.M.E. external pacemaker attached to the catheter electrode, using a 4-volt pulse, and at a rate of 140/min. The diathermy point of an American Cystoscope Co. diathermy machine was then applied to the muscle in the thoracotomy incision. An immediate buzzing in the pacemaker unit heralded the almost instantaneous onset of fibrillation. At first it was thought that the hazard was due to contact of the pacemaker unit with the metal of the operating-table—perhaps allowing leakage current to interfere with the pacemaker.

These were the circumstances that prevailed during the two operations (Cases 1 and 2) described. However, it was found that the same responses occurred when the pacemaker unit was completely isolated from the table.

Experiment II.—10 August 1964. A sheep was similarly prepared by right thoracotomy, and a bipolar cardiac catheter electrode inserted into the right ventricle. The animal heart rate—at 110/min.—was paced (using the I.M.E. model pacemaker) at 120/min. with a 4-volt pulse. When the diathermy point was applied to the subcutaneous tissue the pacemaker again "buzzed," indicating a high-frequency response, and the heart immediately fibrillated.

As we have never been able to correct established ventricular fibrillation in the sheep by either A.C. or D.C. defibrillation it was decided to repeat these experiments in the dog, in which defibrillation is readily accomplished.

Experiment III.—17 August 1964. The same experiment was performed on a dog, testing the I.M.E. model pacemaker. Diathermy applied to the chest wall induced ventricular fibrillation that proved unusually refractory to correction with the A.C. defibrillator. Single shocks and several series of repeated shocks at first failed to correct the fibrillation. Only after using intracardiac adrenaline 1/10,000 solution was defibrillation finally achieved and a spontaneous heart-beat restored. The bipolar catheter electrode was left within the right ventricle, but *disconnected from the pacemaker,* and diathermy again used. The heart remained in normal rhythm. The bipolar catheter electrode was next attached to the pacemaker *without using any pacing current.* When the diathermy was used again ventricular fibrillation did not occur. When *the pacemaker was now turned on* to a 1-volt pulse, and the diathermy used, transient ventricular fibrillation occurred, and

was followed by spontaneous recovery. With a 2-volt pulse fibrillation was produced which required vigorous measures to secure defibrillation. With a 3-volt pulse intractable ventricular fibrillation was produced. Whenever the pacemaker was used with a voltage indication set in any other than the "off" position an audible buzz occurred through the pacemaker speaker. In all these experiments there was a short latent period between using the diathermy and the onset of ventricular fibrillation.

Experiment IV.—18 September 1964. The experiments were repeated (I.M.E. model pacemaker) using a *unipolar intracardiac pacemaker electrode* with the indifferent electrode attached to the muscle in the thoracotomy incision. Fibrillation set in immediately on applying diathermy current to the chest wall. The action on the heart was mimicked at the site of the attachment of the indifferent electrode, where tetanic spasm of muscle was evident during the time of stimulation by the diathermy current. It was surmised that the bipolar electrode in the right ventricle, surrounded by blood and lying in the frequency field of the short-wave diathermy machine, acted as a receiver of the radio-frequency waves emitted by the diathermy machine. This "current" passed up the bipolar leads, upset the normal slow rhythm of the oscillator in the pacemaker, and initiated a high-frequency pulse which was audible in the pacemaker speaker. This high-frequency pulse then reached the heart, via the electrodes, and, at as low as 1-volt potential, was of a frequency that caused ventricular fibrillation.

Experiment V.—21 August 1964. A sheep was prepared with an intracardiac bipolar electrode, and the I.M.E. external pacemaker was set at 132 beats/min. with a 2-volt stimulus. It was tested against an American Cystoscope Co. diathermy machine. With the animal lying on the indifferent electrode, and with the active electrode completely disconnected from the diathermy machine, a fibrillating response occurred in the heart as soon as the foot switch was depressed. The machine was also tested without connecting the indifferent electrode. Ventricular fibrillation occurred when the current was switched on with the active electrode held *as far as 33 in. (84 cm.) from the animal.* No contact whatever was made with the animal.

As these effects were produced by radio-frequency waves it seemed advisable to determine the effects of other apparatus emitting the same type of wave.

Other Machines Tested

Portable Diathermy Machine—Hyfrecator

A small diathermy machine called a Hyfrecator is owned and operated by many general practitioners, and used in their consulting-rooms for removing warts, corns, and callosities. This machine is made by the Birtcher Corporation, and when connected to a 230-volt supply consumes 60 watts. It generates radio-frequency waves similar to larger surgical diathermy units (2,500 kc./sec.)

Experiment VI.—6 October 1964. In an anaesthetized sheep, pacemaker leads were sewn into the myocardium and attached to the I.M.E. pacemaker, which was set at 120 oscillations/min. and at a 1-volt output. The Hyfrecator was tested at its half-strength position, the one customarily used. When the Hyfrecator electrode was held *more than 2 ft. (60 cm.)* away from the animal the heart immediately fibrillated.

The Hyfrecator was later tested on a Tektronix oscilloscope. Its wave form was one megacycle, and was irregular in its radio-intensity. To a patient whose heart is stimulated by the pacemakers tested, this machine is therefore as lethal as any other diathermy machine.

Short-wave Diathermy for Physiotherapy

Because of the almost identical electrical field created in a patient by short-wave diathermy as used by physiotherapists, we tested such a unit to see whether it, too, would produce ventricular fibrillation when applied to the limb of a sheep whose heart was paced by a pacemaker.

Experiment VII.—14 September 1964. The heart of an anaesthetized sheep was exposed by right thoracotomy, and a bipolar catheter electrode inserted into the right ventricle through the right external jugular vein. The heart rate was controlled with the I.M.E. pacemaker at 140 beats/min., using a 4-volt pulse. The applicators of a Liebel Flarsheim Co. shortwave diathermy machine were placed across the right hind thigh. With a "condenser field" method of application, and with the capacity increasing to 300 watts at 27.12 Mc./sec., the pacemaker was immediately activated to a high-frequency response, after which the heart fibrillated.

Ultra-violet-light Machines

The Fitzgerald Manufacturing Co., of Torrington, Conn., U.S.A., market a Vioray local ultra-violet-light stimulation apparatus for domestic use. This machine contains a high-frequency, high-voltage generator whose output is fed into a glass electrode in the form of a comb or pad, or into a metal electrode. It oscillates at a variable frequency, as the high-frequency current is generated by a vibrator similar to a domestic door-buzzer. This was tested.

Experiment VIII.—28 September 1964. With the hand-piece of the Vioray machine in one hand and the I.M.E. pacemaker in the other, and set at 72 beats/min. and at a 1-volt pulse, the pacemaker was immediately triggered into a high-frequency response.

Experiment IX.—28 September 1964. With the Vioray machine electrode removed to 6 ft. (1.8 m.) from the I.M.E. pacemaker, it was again activated to a high-frequency response.

Experiment X.—28 September 1964. When tested at a 6-ft. (1.8-m.) distance against an Elema-Schönander (2.5 m.sec.-6-volt) implantable pacemaker attached to a sheep's heart, a similar ventricular fibrillating response occurred.

Experiment XI.—5 October 1964. When tested again at a 6-ft. (1.8-m.) distance against an I.M.E. external pacemaker with leads attached to the heart, ventricular fibrillation occurred.

Comment.—There was no doubt of the lethal nature of the radio-frequency waves from this machine, broadcasting up to a 6-ft. (1.8-m.) distance from an animal with its heart controlled by the external or implanted pacemakers tested. The animal's whole body appeared to act as the "aerial" receiving the radio-waves that triggered the oscillation of the pacemaker into a high-frequency response.

Radio Broadcasting Station

The environs of the transmission units at radio broadcasting stations appeared to be another likely area where radio-frequency could trigger a transistorized pacemaker. The I.M.E. and the Elema-Schönander units were therefore taken to the 4YA, 4ZB, 4YC, DN TV2 transmission stations at Highcliff, Dunedin.

They were *not* activated when in the vicinity of the transmitter cubicles. When, however, the pacemakers were brought to within the safe proximity limit of a coil carrying the radio-frequency of one of these stations, both pacemakers were immediately triggered into the dangerous high-frequency response.

Other High-frequency Sources

The following tests were carried out on the isolated pacemakers. Experimental animals were not used.

Betatron Radiotherapy Apparatus.—(*a*) When the magnet of this machine was energized but not producing *x* rays the I.M.E. pacemaker did not react. (*b*) The injection cabinet contains thyratron valves which control the injection current. When the thyratrons were operating, the trigger pulses to the thyratrons radiated an electrostatic field which made the I.M.E. pacemaker (set at 6–7 volts) unstable when the patient leads were 9 in. (23 cm.) from the valves. The distance from the valves could be reduced as the output voltage control of the pacemaker was reduced. (*c*) The Elema-Schönander pacemaker was not affected until held almost against the valves.

Neon Advertising sign.—(*a*) When the I.M.E. unit was held 6 in. (15 cm.) from the high-voltage leads and the glass tube of the sign (15,000 volts) there was the same high-frequency response. (*b*) When the Elema-Schönander unit was held at 4 in. (10 cm.) from the same sites, only an intermittent response was obtained.

Carbon Arc and Electric Welding Arc.—These were tested with both pacemaker units without any response being noted.

High-frequency and Radar-frequency Machines

The previous experiments indicated that radio-frequencies triggered the response that has been described. It seemed worthwhile to investigate also the effects of radar-frequencies.

Experiment XII.—21 September 1964. A sheep was prepared with a bipolar intracardiac catheter electrode attached to the I.M.E. transistor pacemaker. The heart was exposed. Using the "radar-frequency," Picker-Harting Thermatron unipolar beamed micro-wave machine with an output power of 125 watts at 2,425 Mc./sec., directed firstly at the right hind limb, and later direct on to the exposed heart, there was no triggering of the pacemaker. These fields caused heating. There was similarly no triggering with the Microtron 200 microwave diathermy unit, made by Electro-Medical Supplies, Great Portland Street, London.

Up to this stage in the investigation all the experiments had been carried out with the only two pacemakers in use in our unit—that is, the I.M.E. model external pacemaker, made by Genito-Urinary Manufacturing Co., London, and the Elema-Schönander internal pacemaker. We therefore asked the Physics Department of the University of Otago to inspect the I.M.E. model pacemaker to determine the exact mechanism of the interference, and to see whether this could be overcome. At the same time we made efforts to borrow other makes of pacemaker for testing to see whether safer models existed.

On examination it was apparent that the design of the circuit in the I.M.E. external pacemaker is responsible for its unstable state when subjected to radio-frequency stimuli.

This also applies to the Elema-Schönander implantable unit, although it is less sensitive, probably owing to a slight variation in circuit design. (It is impossible to trace the circuit, as the transistors and batteries are completely encased in epoxy resin.)

The I.M.E. model pacemaker is designed around a multivibrator oscillator. The basic circuit is shown in Fig. 1. Transistors A and B are interconnected by two time-constant units (T) in such a way that when transistor A is switched on (conducting) transistor B is switched off (non-conducting). The two transistors cannot be in the same state at the same time, so that the circuit oscillates. The time constants are designed to alter the rate of oscillation, so that for a pulse rate of 60/min. transistor A will conduct for 1 second, and transistor B will conduct for 1.5 m.sec., producing a 1.5 m.sec. pulse at the output terminals.

The unsatisfactory feature of this circuit is that an external signal applied to the output is fed to the base of transistor A and seriously affects the operation of the device. With both the I.M.E. and Elema-Schönander pacemakers a radiated field from diathermy or other equipment, as mentioned earlier, injected into the oscillator via the patient leads will set the unit into a high-frequency oscillation. This high frequency is fed back down the leads to the heart at an amplitude equal to the pacing voltage, and this produces ventricular fibrillation.

The University of Otago Physics Department developed a pacemaker free of the unstable features demonstrated in the circuits employed in the pacemakers we had been using (Fig. 2).

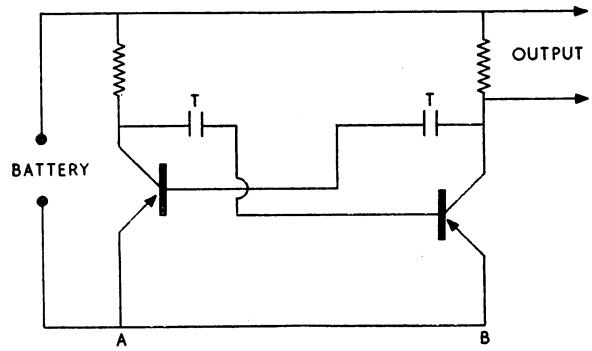

FIG. 1.—The basic circuit of the I.M.E. model pacemaker (see text).

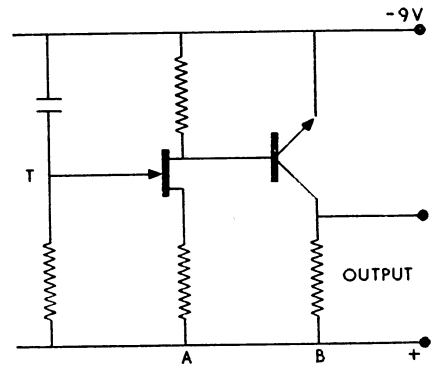

FIG. 2.—The oscillating circuit consists of transistors (A) and the time-constant network (T), which controls the rate of A. The output pulse is fed into transistor (B), which shapes the pulse to 1.5 m.sec. square waves with a 9-volt maximal amplitude. The impedance of the circuit being low, radio-frequency signals injected into it will not affect its output.

This unit uses a unijunction transistor to generate pulses in a low-impedance circuit; the pulses are available at the output of an isolating amplifier stage.

The prototype is under test and has given excellent results to date. Ventricular fibrillation has *not* been produced by surgical diathermy applied direct to the myocardium of an experimental animal with the heart paced by this unit.

The following experiments were done to demonstrate the safety of the prototype pacemaker in regard to freedom from interference by radio-frequency waves.

Experiment XIII.—23 October 1964. A right thoracotomy was performed in a sheep, and the electrodes of the University of Otago pacemaker were then attached to the ventricles, which were paced at 120 beats/min. with a 3-volt pulse. The American Cystoscope Co. diathermy machine was then tested against it with both "cutting" and "coagulating" currents used at top capacity. The paced heart was immune to radio-frequency when tested as follows: (*a*) with no electrode

attached to the animal but with diathermy machine activated; (*b*) with the animal lying on the activated indifferent electrode; and (*c*) with the animal lying on the "indifferent" electrode, and with the "positive" electrode incising in turn skin, chest-wall muscle, pericardium, and myocardium. Throughout the test the heart-beat remained in normal rhythm.

As a control, the University of Otago pacemaker was removed and the I.M.E. pacemaker again tested, by placing the animal on the "indifferent" electrode alone. Immediately the diathermy machine was activated fatal ventricular fibrillation occurred.

That the Otago University pacemaker could in fact pace the heart was clearly demonstrated in experiments of 2 and 16 November, when complete heart-block was induced by techniques already described (Borrie and Lichter, 1964). The heart with complete heart-block could then be paced in response to the pulse emitted by the pacemaker.

Other Pacemakers Tested

It was found that the hazards described do not apply to the Medtronic, Devices, or Corbin–Farnsworth pacemakers, these being the only pacemakers available to us for testing.

The following experiments were carried out.

Experiments XIV–XVI.—With the technique described in experiment XIII, tests were made of the Medtronic unit (experiment XIV, 6 November), the Devices unit (experiment XV, 9 November), and the Corbin-Farnsworth pacemaker (experiment XVI, 16 November). Each of these units has a pulse "generator" separate from the pulse "shaper." In none of these three experiments did ventricular fibrillation occur.

After each unit had been checked the control experiment of checking the I.M.E. pacemaker was again performed, with the onset of fatal ventricular fibrillation in each instance.

Discussion

These clinical and experimental findings indicate the hazards associated with the use of diathermy and other radio-frequency apparatus in the presence of certain implantable pacemakers whose electric circuits are sensitive to radio-frequency.

The implications are obvious. Surgical diathermy units must not be used in the performance of any operation on a patient whose heart is being stimulated by an external or implanted pacemaker with this type of circuit. Indeed, a diathermy machine must not even be switched on near such a patient. He must be warned of the danger of having treatment of his warts or callosities by Hyfrecator, or a trans-urethral resection of an enlarged prostate gland by diathermy current. He must never have short-wave-diathermy treatment—for example, for a painful hip-joint or knee-joint. He must never use Vioray-type ultra-violet light for skin rashes or baldness, and he should never go close to neon advertising signs or sources of high-tension currents such as radio-broadcasting transmitters, betatron therapy units, or industrial thyratron type control equipment with a high current-control value, operated by an injection pulse.

All of these may cause death by ventricular fibrillation in a patient with an implanted pacemaker whose electric circuit is sensitive to radio-frequency waves.

X-ray currents *do not* trigger such pacemakers to this high-frequency response. Our patients all have routine post-operative chest films taken, and one, reported elsewhere (Borrie and Lichter, 1964), whose unit was changed after 21 months and required rechecking six weeks later, was later examined by fluoroscopy without any adverse effect on his heart-rate.

Summary

Surgical diathermy or physiotherapy short-wave diathermy apparatus must never be used near a patient whose heart is being paced by an artificial pacemaker with an electric circuit sensitive to radio-frequency-wave interference. The I.M.E. and Elema-Schönander pacemakers have been shown to exhibit this sensitivity.

This hazard was first demonstrated when ventricular fibrillation occurred during the implanting of a pacemaker in two patients who, as a preliminary to the definitive operation, had bipolar intracardiac catheter electrodes inserted and cardiac stimulation provided by an external battery-operated transistor pacemaker (I.M.E. model G.U. 2371). The onset of fibrillation was associated with the use of surgical diathermy during thoracotomy.

Animal experiments confirmed that surgical diathermy, and indeed many other types of apparatus emitting radio-frequency waves, will produce ventricular fibrillation in the presence of an external or implanted pacemaker whose electric circuit is sensitive to such waves.

The pieces of apparatus tested were: (*a*) American Cystoscope Co. diathermy machine; (*b*) Birtcher Corporation Hyfrecator; (*c*) Liebel Flarsheim Co. short-wave diathermy; (*d*) Fitzgerald Manufacturing Co. Vioray ultra-violet-light machine; (*e*) Picker-Harting Thermatron.

The hazard is most likely to occur when surgical diathermy is used in operations for implanting pacemakers, or in any subsequent operation the patient may require. Disasters however, may also occur with the seemingly innocuous use of short-wave diathermy for treating lesions distant from the heart, such as a painful limb, or when using certain types of ultra-violet-ray apparatus. There are dangers, too, near a radio transmitting station, betatron therapy apparatus, or certain types of industrial electronic control equipment.

No direct physical contact with the apparatus is required to produce such fatal ventricular fibrillation, which has been shown to occur when using apparatus emitting radio-frequency waves of the order of 500 kc./sec. to 30 Mc./sec.

Radar frequency of the order of 2,250 Mc./sec. does not affect the electrical circuit of such a pacemaker. Heat generated by such a unit, however, may heat the electrodes to a temperature that will burn the heart or destroy the pacemaker.

We have been unable to test a wide variety of pacemakers, as only those described in this paper were available to us. Other makes may also be subject to this dangerous sensitivity to radio-frequency-wave interference. It has, however, been shown that the Medtronic, Devices, and Corbin-Farnsworth pacemakers are free of the hazards here described. The Physics Department of the University of Otago has also made a pacemaker that is free from such interference, and this prototype is giving excellent results in trials.

Addendum.—Since completing this paper we have read the paper of Jessen and Rosen (1963). They state: "As our experience of the influence of other electrical devices upon the pacemaker is limited, we advise patients to be careful in their use of electrical appliances. Even a fraction of the usual 220 volts A.C. (50 cycles per second) may lead to ventricular fibrillation. We caution against roentgen therapy, diathermia, and electrocoagulation, while we believe that conventional roentgen examination is permissible. In special circumstances the patient is warned against coming into contact with radio transmitters and radar and other installations which may affect the pacemaker circuit." Our clinical and experimental

experience provides the substance for Jessen and Rosen's caution.

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Classification of Chest Injuries as an Aid to Treatment

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Intermittent positive-pressure respiration (I.P.P.R.) is now recognized as having an important part to play in the treatment of chest injuries (Barrett, 1960 ; Griffiths, 1960 ; Windsor and Dwyer, 1961 ; Garden and Mackenzie, 1963). Although treatment by this method gives good results, it should not be applied where a simpler method would suffice. I.P.P.R. is a severe strain on nursing staff, and because of its complexity carries a morbidity and even a mortality of its own.

We have found it of practical value to consider the treatment of patients with chest injuries in three phases. (1) *The emergency treatment* of a number of conditions common to many chest injuries. These conditions include pain, pulmonary compression, paradoxical respiration, lung contusion, shock, and coexisting injuries. (2) *The classification of patients* in mild, moderate, and severe groups by ventilatory capacity, and not by the anatomical extent of the injury ; and the institution of the appropriate treatment. (3) *The maintenance of treatment.*

There are two factors which complicate the treatment of chest injuries and therefore the description of treatment. The first is that the conditions referred to under heading No. 1 above are interrelated. If pain is relieved the amount of paradoxical movement of the chest wall may decrease, and where a complicated form of treatment seemed inevitable a simpler one may suffice. The second is that although some patients can be placed in the correct group when first seen, in others the effect of treatment of the conditions mentioned under heading No. 1 must be observed before classification can be effected. Other patients, again, may move from one group to another during treatment.

The treatment of chest injuries will therefore be described by amplifying the headings mentioned above, although this means that the most important part of the communication—the classification of patients—appears late. The results of treatment of 121 patients, with illustrative case reports, are also presented.

Conditions Common to Many Chest Injuries

Pain

All except very minor chest injuries are painful. The patient in pain is handicapped in two ways: ineffective coughing leads to bronchial obstruction by mucus with absorption of air distal to the block and consequent atelectasis. His breathing is shallow, and this (Ferris and Pollard, 1960) leads to a progressive fall in lung compliance owing to diffuse closure of alveoli throughout the lung substance. Pain prevents him from reversing this tendency by deep breathing.

Pain can be controlled by conventional analgesics with or without antagonists and by thoracic segmental extradural block. We have used morphine alone and in combination with amiphenazole or tetrahydroaminacrine. Both these antagonists allow a larger dose of morphine to be given without respiratory depression. We have obtained good results with a combination of morphine 15 mg. and tetrahydroaminacrine 20 mg.

Segmental thoracic extradural block (Simpson *et al.*, 1961) involves the injection of local analgesic solution through a polyvinyl catheter placed in the thoracic extradural space. This provides complete relief from pain in the affected segments, and the restricted area of analgesia allows the use of small amounts of local anaesthetic solution, so that the fall in blood-pressure which accompanies an extensive extradural block is avoided. The relief from pain enables suitable patients to clear their lower airway by coughing and enables them to rest, and it improves morale. It will also, by allowing the patient to breathe more deeply and slowly, diminish the amount of paradoxical movement of a "floating" segment of chest wall. Continuous analgesia can be maintained by injections of lignocaine 1.5% through the catheter at intervals of 90 to 120 minutes, or by amethocaine (Pantocaine Plombe) at intervals of about three hours. An injection before physiotherapy allows coughing and deep breathing and will often be sufficient to prevent pulmonary complications. Conventional analgesics will also be necessary when the extradural analgesia is not continuous. A rigid aseptic technique for introducing the catheter is obligatory. Infection has not occurred in our patients in spite of the fact that catheters are sometimes left in place for long periods—in one case for 25 days.

Pulmonary Compression

Either pneumothorax or haemothorax, or both, will compress the lungs. If a leak from an air passage to the pleural space is valvular a tension pneumothorax may develop and affect not only ventilation but venous return to the right side of the heart. Tension pneumothorax may endanger life and require urgent treatment by inserting into the pleural cavity a drain connected to an underwater seal. The drain is usually placed in the second anterior intercostal space, and an emergency underwater seal drain may be made from a transfusion set. If there is evidence of blood in the pleural cavity a tube of larger bore

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